

X-ray vs. Optical Variations in the Seyfert 1 Nucleus NGC 3516: A Puzzling Disconnectedness

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ABSTRACT

We present optical broadband (B and R) observations of the Seyfert 1 nucleus NGC 3516, obtained at Wise Observatory from March 1997 to March 2002, contemporaneously with X-ray 2-10 keV measurements with RXTE. With these data we increase the temporal baseline of this dataset to 5 years, more than triple to the coverage we have previously presented for this object. Analysis of the new data does not confirm the 100-day lag of X-ray behind optical variations, tentatively reported in our previous work. Indeed, excluding the first year's data, which drive the previous result, there is no significant correlation at any lag between the X-ray and optical bands. We also find no correlation at any lag between optical flux and various X-ray hardness ratios. We conclude that the close relation observed between the bands during the first year of our program was either a fluke, or perhaps the result of the exceptionally bright state of NGC 3516 in 1997, to which it has yet to return. Reviewing the results of published joint X-ray and UV/optical Seyfert monitoring programs, we speculate that there are at least two components or mechanisms contributing to the X-ray continuum emission up to 10 keV: a soft component that is correlated with UV/optical variations on timescales $\gtrsim 1~\mathrm{day},$ and whose presence can be detected when the source is observed at low enough energies (\sim 1keV), is unabsorbed, or is in a sufficiently bright phase; and a hard component whose variations are uncorrelated with the UV/optical.

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Subject headings: galaxies: active - galaxies: individual (NGC 3516) - galaxies:

Seyfert - x-rays: galaxies

1. Introduction

The paradigm that active galactic nuclei (AGNs) are powered by accretion onto massive black holes (MBHs) has recently gained strong observational support, with the detection, in several AGNs, of X-ray emission lines that are though to be broadened by relativistic effects near the MBH horizon (Nandra et al. 1997; Sako et al. 2002), the evidence for dormant black holes in many normal nearby galaxies (Gebhardt et al. 2000; Ferrarese et al. 2000), and the estimates of MBH masses in several tens of AGNs via reverberation mapping (Kaspi et al. 2000). However, the detailed mechanisms by which accretion produces the observed spectral energy distributions, as well as other properties, of AGNs are unknown, and observations have placed few constraints on the many theoretical scenarios proposed.

It has been hoped that flux variations in different energy bands would provide clues toward understanding the AGN emission processes. In particular, a number of bright Seyfert-1 galaxies have been subject to contemporaneous X-ray and UV/optical monitoring aimed at detecting inter-band lags, which could etablish a relation between emission components, e.g., by identifying the primary and secondary (i.e., reprocessed) emissions (Done et al. 1990; Clavel et al. 1992; Kaspi et al. 1996; Crenshaw et al. 1996; Warwick et al. 1996; Edelson et al. 1996; Nandra et al. 1998; Edelson et al. 2000; Chiang et al. 2000; Uttley et al. 2000; Peterson et al. 2000; Pounds et al. 2001; Turner et al. 2001; Collier et al. 2001; Shemmer et al. 2001). However, the results of these programs, which have searched for correlations and lags on timescales of hours to weeks, have not been conclusive. It is generally true that UV/optical variation amplitudes are much smaller than those in the X-rays, which could argue that the X-rays are the primary emission. Clear lags between X-ray and UV/optical variations have not been seen. In those cases where correlation at a lag between different X-ray bands has been detected (sometimes with debatable significance), the lag increased with band energy, indicating the X-rays are secondary (e.g. Chiang et al. 2000). In a variant on the idea of searching for correlations between fluxes at different bands, Nandra et al. (2000) found that the X-ray spectral index in NGC 7469 was correlated with UV flux at zero lag during a month-long campign on this Seyfert 1 galaxy. Papadakis, Nandra, & Kazanas (2001) have analyzed the cross-spectrum of variations in several X-ray bands in this object, and found that harder X-rays are delayed with respect to soft ones, with the delay proportional to the Fourier period probed. Such behavior is

common in Galactic black hole binaries, but several competing theoretical explanations exist for it.

The studies mentioned above have tended to be of limited duration - often just a few days (Peterson et al. 2000 being the main exception). A potential pitfall of short duration studies is that they may detect few or no large-amplitude variation events with which to search for inter-band correlations. Furthermore, the results of variability studies may depend on the timescale sampled, and different behavior may pertain to different sources. In 1997 we initiated a long-term X-ray/optical program to monitor continuously several Seyfert 1 galaxies, such that month- and year-long variation timescales can be properly probed, as well as shorter timescales. X-ray observations are obtained with the Rossi X-ray Timing Explorer (RXTE), and optical data are from the Wise Observatory 1m telescope. In Maoz, Edelson, & Nandra (2000, hereafter Paper I), we presented the first 1.5 year of X-ray and optical data for NGC 3516. Paper I found that the low-frequency component of the X-ray variations appeared to mimick closely the optical variation during the first year, but with a lag of ~ 100 days. However, this correlation ceased in the last 6 months of the data. The significance of the correlation we found was high, based on detailed Monte-Carlo simulations, and making reasonable assumptions about the intrinsic optical power spectrum (see Paper I). Although we proposed some physical explanations for it, we cautioned that the correlation was driven by a single variation "event" and could therefore be a statistical coincidence. Here, we revisit NGC 3516 after having accumulated 5 years of contemporaneous X-ray and optical data.

2. Optical and X-ray Light Curves

The optical data presented in this paper span the period from 1997, March 5, to 2002, March 7, and were obtained with the Wise Observatory 1m telescope in Mitzpe Ramon, Israel. On the nights when the galaxy was observed, Johnson-Cousins B- and R-band images were obtained once per night. We used a 1024×1024 -pixel thinned Tektronix CCD at the Cassegrain focus, with a scale of 0.7'' pixel⁻¹. Exposure times were 3 min in R and 5 min in R. During this 1828-day period, useful data were obtained for 209 epochs in R and for 184 epochs in R. The reader is referred to Paper I for details of the optical data reduction, aperture photometry, and derivation of light curves relative to comparison stars (up to six) in each frame.

Figure 1 shows the optical light curves we have obtained for NGC 3516. In Figure 2 we plot on the same scale for each optical band the constant, to within errors, light curve of one of the comparison stars, calculated relative to the other five stars. As in Paper I, the

R and B light curves of NGC 3516 in Figure 1 show very similar variability patterns, with peak-to-peak amplitudes of 0.5 mag and 0.9 mag, respectively. The exact amplitude of the variations depends on the choice of photometric extraction aperture, which will include a particular fraction of stellar light from the galaxy. The above numbers are therefore lower limits on the *intrinsic* variability amplitude of the nucleus in each band, which is difficult to estimate. Galaxy contamination is larger in the R band, and at least some of the difference in amplitude between B and R variations is due to this. In the last epoch presented here, the optical flux was at its lowest in the past 5 years, and falling.

The observations and reduction leading to the new RXTE data we present are as described in Edelson & Nandra (1999), but using the most up to date background and calibration files. The RXTE data span the period from 1997, March 15 to 2002, February 26. Up until 2000, Feb 18, the sampling interval between points was generally about 4.3 days, except for several periods of more intense monitoring. Then, after a 140-day period when RXTE did not observe NGC 3516, the monitoring resumed and continued with a sampling interval of about 17 days, except for a continuous 110 ks scan on 2001 April 10-11. Continued RXTE monitoring beyond our last measured point has not been approved.

Since the R and B light curves are very similar, we will refer to them collectively as "the optical light curve". We will use mainly the R light curve, which is slightly better sampled than B, in the figures and discussion below. Figure 3 (top panel) shows again the R light curve of NGC 3516, but with a relative linear (rather than magnitude) flux scale. The bottom panel shows the RXTE X-ray (2-10 keV) light curve. As found in Paper I, which covered the first one-third of the baseline shown in Fig. 3, the X-ray light curve has much larger variation amplitude than the the optical, particularly at short timescales. In the last 3 years, or so, the nucleus is faint relative to the first year, in the X-rays as well as in the optical, if one ignores the occasional large X-ray flicker on small timescales.

As mentioned in $\S1$, a central and surprising result in Paper I was an apparent optical-to-X-ray cross-correlation signal at ~ 100 day lag, driven by the slow component of an outburst that appears in Figure 3 between days 600 and 900 in the optical, and between days 700 and 1000 in X-rays. We revisit this issue now with our much-expanded dataset. To isolate the relative contributions to the light curves and the correlations made by fast and slow variations, we have smoothed the light curves with a 30-day boxcar running mean. In addition to the unaltered light curves, we examine these smoothed versions and the residual light curves (i.e., the original light curves minus their respective smoothed versions).

Figure 4 shows the smoothed X-ray and optical light curves superimposed. To facilitate comparison of the two, all fluxes are plotted on a relative linear scale, but the amplitude of the smoothed X-ray variations have been scaled down by a factor of 4. The top panel

shows the two light curves with no lag, and the bottom panel shows them with the X-rays advanced by 100 days. Clearly, the match of the first year at 100-day lag does not persist or repeat in the new data. Furthermore, a correlation at zero lag, noted in Paper I, and driven by the simultaneous dip in the light curves around day 1000, does not hold up. To study this question more quantitatively, and see if there are some other lags at which any of the light curves are correlated, we have calculated the cross-correlation functions among the various light curves. The z-transformed discrete correlation function (ZDCF; Alexander 1997), a modification of the discrete correlation function (Edelson & Krolik 1988) was used.

Figure 5, top left panel, shows the cross-correlation between B and R. The high peak is at zero lag, confirming a result from Paper I. The top right panel shows the ZDCF between the residual (i.e., after subtraction of a smoothed version) B and R light curves. The null correlation between these close bands, expecially around zero lag, suggests that the short-timescale variations in the optical light curves (or at least in one of them) are dominated by measurement error. This is not surprising, given the estimated errors, and the small amplitude of the actual fast optical variations, as previously quantified in this object in more sensitive and densely sampled HST data (Edelson et al. 2000).

The bottom left panel of Fig. 5 cross correlates the R-band and 2-10 keV light curves. A peak is seen at a lag of about 100 days, in the sense that X-rays lag the optical. The bottom-right panel shows the ZDCF for the smoothed optical and X-ray light curves. The peak correlation at 100-day lag is strengthened, indicating it is driven by the slow components of the light curves. The position and height of the ZDCF peaks in the latter two plots are very similar to those found in Paper I, based on the first one-third of the data. Moreover, various other large maxima and minima that appeared in these cross-correlations in Paper I do not appear in the present, expanded, dataset, arguing that those peaks, at least, were artifacts of the sampling.

However, it is easy to confirm formally the visual impression from Fig. 4, that the correlation at 100 days is still driven only by the first year's outburst. Figure 6, top-left panel, correlates the smoothed X-ray and optical light curves, but excluding the first year's data. The peak at 100 days is gone, and there is no clear and significant signal at any lag. The top right panel of Fig. 6 shows that there is also no clear correlation between the fast components of the B and X-ray light curves, as represented by the residual light curves. Note, however, that the point at zero lag is the highest. Possibly there is, buried inside the optical light curves, a positive correlation with the X-rays, which could be recovered if the optical measurements had milli-magnitude accuracies, rather than a few percent. Reaching such accuracies is probably unrealistic in ground-based observations of a point source (the AGN) on a bright galaxy background, but could be achieved with a photometrically stable

space telescope. On the other hand, Edelson et al. (2000) carried out such an experiment (albeit limited to 3 days duration) and did not find such a correlation.

Finally, we investigate whether the optical and X-ray variations can be related via some observable other than the total flux. Following the lead of Nandra et al. (2000, see §1), we have calculated the ZDCFs of the optical light curve vs the "softness" ratio of counts in different X-ray bands. Testing among the various X-ray count ratios that can be formed from the 2-4 keV, 4-7 keV, and 7-10 keV bands, their smoothed versions, and the various optical light curves, we find no case of a clear correlation. For example, the bottom panels of Fig. 6 show the ZDCFs of R vs the 4-7 keV/7-10 keV count ratio, for both smoothed and unsmoothed light curves. Interestingly, although there is no single clear peak, there is a fairly high correlation plateau between about zero and 400 days lag. The source of this can be seen in Fig. 7, which compares the optical light curve to the smoothed 4-7 keV/7-10 keV ratio curve. Both time series are plotted on a relative scale. One sees that, although there is no one-to-one correspondence among the light curves, the X-ray spectrum was softer until March 1999, when the optical flux was generally high, than after May 1999, when the optical flux was generally low. It is the lack of detailed correspondence in this trend that washes out the correlation to a broad plateau in the ZDCF. Naturally, we cannot say whether this trend is real, as it is based not even on a full "event" (e.g. a rise and fall) in the light curves. We also note that there is no analogous effect at lower X-ray energies, as seen in the relative 2-4 keV/4-7 keV ratio plotted in the bottom panel of in Fig. 7.

3. Discussion

Much current thinking about the emission processes in AGNs centers around the notion that the X-rays arise from very close (within a few Schwarzschild radii) of a massive black hole. Support for this idea has come from the rapid variability that is observed in X-rays (implying small physical scales), as well as the detection in X-rays of a broad Fe K-shell emission line in many Seyfert 1s (e.g., Nandra et al. 1997). The emission line is thought to be gravitationally and Doppler broadened fluorescence of the inner parts of an accretion disk, after the disk is illuminated by the X-rays. More recently, such relativistic emission lines from the Ly α transitions of several hydrogen-like ions may have been detected in XMM-Newton data for two Seyfert galaxies (Branduardi-Raymont et al. 2001; Sako et al. 2002), though this claim has been contested using Chandra data (Lee et al. 2001). The continuum-emission mechanism is not known, but most commonly it is assumed that the X-rays are optical/UV photons which have been upscattered by a population of hot electrons (e.g., Sunyaev & Truemper 1979). The acceleration mechanism and geometry of

the X-ray source is not known. Neither is the source of seed photons, and despite some substantial problems it is still usually assumed that the optical/UV arises directly from an accretion disk (Shields 1978; Malkan 1983). It has also been hypothesized that X-rays illuminating the disk, or other optically thick gas, might be responsible for some or all of the optical/UV radiation via reprocessing (Guilbert & Rees 1988; Clavel et al. 1992).

Variability data such as those we have presented above can provide constraints on possible models. In summary of the observational results, we have found a similarity between the optical and X-ray light curves during the first year of our program, when optically the source was particularly bright, and with the X-rays lagging the optical variations by about 100 days. This correlation disappeared in the last 4 years of the data, during which we see no clear correspondence at any lag between the optical and the X-rays. Furthermore we do not find any clear trends when we examine X-ray hardness ratios, rather than fluxes. The only positive signals we find are a hint that there may be a intrinsic correlation between fast optical and X-ray variations with little lag, and a rough trend for a softer spectrum in the 4-10 keV range when the source is optically brighter.

Phenomenologically, the reality of even these relations is debatable, and all of them may be chance coincidences. A more stringent test must await the results of continued monitoring, during which NGC 3516 may perhaps recover to the high optical brightness it attained between mid-1997 and mid-1998. The lack of any straightforward correlation between X-ray and optical fluxes, in its simplest interpretation, argues that there is no physical relation between the emission in the two bands, except perhaps that both ultimately derive their energy from the central black hole. If there is a connection between the emission mechanisms in these two wavelength regimes, at the very least it must be complex enough to wash out any evidence for it in the variability data.

Is NGC 3516 peculiar among AGNs in its lack of a clear correlation between X-ray and optical/UV fluxes? To address this, we critically review the results of previous campaigns on this and other Seyfert galaxies.

NGC 4051 Done et al. (1990) monitored NGC 4051 for 2 days, and found no correspondence between the large-alplitude 2-10 keV variations seen with *Ginga* and the constant (to < 1%) optical flux. Peterson et al. (2000) monitored this galaxy for 3 years with *RXTE* at 2-10 keV and with ground-based optical spectroscopy. Typical sampling intervals were 1-2 weeks in both wavelength regimes. In the third year, the source went into an extremely low X-ray state. While confirming the lack of correlation found by Done et al. (1990) on short timescales, Peterson et al. (2000) found that the light curves are correlated after smoothing on 30-day timescales. NGC 5548 Clavel et al. (1992) observed NGC 5548 simultaneously with *Ginga* at 2-10 keV and with *IUE* at 1350 Å over a period spanning 51

days. The source brightness was lower than average both in UV and in X-rays. The authors claimed a significant correlation, yet this was based on nine epochs, and basically one-half of an "event" in the light curves. Chiang et al. (2000) observed NGC 5548 for 2.8 days simultaneously with EUVE (0.14-0.18 keV), ASCA (0.5-1 keV), and RXTE (2-20 keV), with 44 EUVE epochs. They found a good correlation between the three bands, but as in the previous experiment on this object by Clavel et al. (1992), the correlation is dominated by a single "step" in the light curves. The connection of the extreme-UV with the UV range was previously given by Marshall et al. (1997) who compared EUVE measurements to IUE and HST UV observations, but the correlation they claimed was based on 10 data points spaced over 10 days, and a low correlation coefficient.

NGC 4151 Edelson et al. (1996) compared 17 epochs of Rosat 1-2 keV (Warwick et al. 1996), IUE ultraviolet (Crenshaw et al. 1996), and Wise Observatory optical (Kaspi et al. 1996) measurements of NGC 4151 which were comtemporaneous over 10 days. The source was near its peak historical brightness. In this case, the light curves at all bands showed convincing similarities on ~ 1-day timescales. However, the X-ray light curves had an overall rising trend during the 10-day period, whereas a constant or falling trend was seen in the UV and optical light curves. Thus, the X-ray to UV/optical correspondence was far from perfect, and in some sense opposed.

NGC 7469 Nandra et al. (1998) observed NGC 7469 for over a period of 30 days with 30 epochs (after averaging) and found that the *RXTE* 2-10 keV and *IUE* UV fluxes were poorly correlated. Nandra et al. (2000) then found in these data a better correlation of the UV flux with the X-ray slope, rather than X-ray flux. The object was close to its average brightness in X-rays and in UV.

Akn 564 This narrow-line Seyfert 1 was monitored approximately daily for 50 days in the optical (Shemmer et al. 2001), in the UV with HST (Collier et al. 2001), and in the X-rays with ASCA at 0.7-1.3 keV (Turner et al. 2001) and with RXTE at 2-10 keV (Pounds et al. 2001). Although variation amplitudes in the UV and optical were only of order a few percent, a high correlation at < 1 day lag between UV and X-ray was reported by Shemmer et al. (2001), as well as a correlation between X-ray and optical, if only a particular segment of the optical light curve, surrounding a relatively large event, is used in the analysis.

NGC 3516 Edelson et al. (2000) monitored NGC 3516 continuously for 3 days with RXTE and ASCA at 2-10 keV, and with HST in the optical. They found no significant correlation between X-ray and optical variations. Those observations took place on days 917-920 (see Fig. 4) when the source optical brightness was average but the X-ray flux was relatively high. In the present work on this AGN, we find no correlation between optical and 2-10 keV variations on timescales of days to 5 years, except possibly a 100-day delayed correlation during 1997-1998, when the source was extremely bright. We do not see a correlation with X-ray slope analogous to that found in NGC 7469 by Nandra et al. (2000).

If we now attempt to synthesize the above results, the following picture emerges. There have been several cases of little or no correspondence between X-ray and UV/optical variability. There have also been several cases where a correlation has been claimed, but the result is not conclusive due to poor sampling, insufficient variability, or low significance. The most convincing flux correlation has been seen by Edelson et al. (1996) between soft (1-2 keV) X-rays and UV/optical flux in NGC 4151, yet, as mentioned above, the longterm trends in the two bands were opposed. The correlation between UV flux and X-ray slope found in NGC 7469 by Nandra et al. (2000) also seems secure. These latter two results could arise if (but do not necessarily imply that) the UV/optical is better correlated with soft (< 2 keV) X-ray variations than with the hard X-rays. It is also important to note that, in terms of timescales, there has been no evidence in any Seyfert 1 of a relation between X-ray and UV/optical variations at short (< 1 day) timescales, and all claimed correlations have been on ≥ 1 day timescales. The fast variations therefore appear be associated mainly with the harder X-rays. This is supported by the finding by that the X-ray variation power density spectrum flattens with increasing energy in NGC 7469 (Nandra & Papadakis 2002), Akn 564, and Ton S180 (Edelson et al. 2001).

Why, then, is a relation between optical flux and X-ray slope, such as seen in NGC 7469, not seen in NGC 3516 in the present work? It can be argued that, contrary to NGC 7469, NGC 3516 has strong and variable absorption in X-rays, and that this variable absorption decorrelates an intrinsic relation in NGC 3516 that is similar to the one in NGC 7469. Evidence for this can be seen in the fact that, in the present data for NGC 3516, the 4-7 keV and 7-10 keV light curves, as well as the full 2-10 keV light curve are more similar to each other than to the 2-1 keV light curve, where absorption will be strongest.

On the other hand, the X-ray absorption in NGC 3516 is comparable to that in NGC 4151, where a UV-X-ray flux correlation is seen in a band that is only slightly softer than the RXTE band. Perhaps this objection can be overcome by noting that the NGC 4151 correlation was seen when this source was exceptionally bright. If the source brightness is a factor, it can further be argued that a flux correlation was indeed seen in NGC 3516, but only during the first year of our program, when the source was exceptionally bright, as was the case in NGC 4151. Indeed, we note in NGC 3516 that the 2-4/4-7 keV and 4-7/7-10 keV ratios and the total X-ray counts all seem to track each other better during the first 700 days, when the source was brighter. Source brightness could conceivably affect the correlations by making visible the high-energy tail of the actually correlated emission at low energies, or by ionizing the absorbing gas, and thus reducing the decorrelating effect of the variable absorption. The clear change in X-ray spectral softness around day 1300 and the accompanying optical dimming, while not necessarily connected, are at least consistent with the expectation that a more photon-starved corona will produce

a harder spectrum. Alternatively, rather than source brightness playing a role, it may be intrinsic differences between objects. For example, the fast, uncorrelated X-ray emission may be always dominant in NGC 3516, and hence swamp out the soft correlated emission in the light curves.

According to this picture, then, at least two components contribute to the X-ray continuum emission of Seyfert nuclei: a soft component which is temporally related to the UV/optical continuum, and which can be discerned in > 1 keV variability data only when the source is bright enough or relatively unabsorbed; and a fast/hard component that varies independently. We note that by "components" we do not necessarily mean emission from physically distinct regions (e.g., Shih, Iwasawa, & Fabian 2002). Instead, the two components that contribute to the X-rays could arise from the same region via different mechanisms. For example, the physical conditions in the coronal regions could be affected autonomously by two processes, such as by time evolution (e.g. Poutanen and Fabian 1999) and by changes in seed photon input which cause an overall temperature change in all the coronal regions. One or the other of these mechanisms could dominate in a particular source at a particular time and on a particular timescale.

This empirical two-component picture and its underlying drivers could be tested via a monitoring program using high resolution X-ray observations instead of the broad band RXTE data, that would disentangle the variations of the continuum and the absorption features. Another path is to search for the the spectral-slope/optical-flux correlation in other objects, having either strong or weak X-ray absorption. We intend to do this in future papers for NGC 4151, NGC 5548, and PG0804+762.

Future programs can also test an alternative interpretation of all previous results, namely, that there is no real correlation of any sort between variations in optical/UV and X-ray bands. In that case, even the more convincing correlations seen, such as Edelson et al. (1996) and Nandra et al. (2000) are chance coincidences arising in the comparison of unrelated red-noise light curves. The detailed simulations performed in Paper I and in Nandra et al. (2000) suggest that this is unlikely, but of course a non-zero probability for a coincidence exists. The simulations themselves can also be refined, e.g., simulated light curves can include amplitude randomization (Timmer & Koenig 1995) as well as phase randomization, and the input assumptions regarding the power spectrum in the various bands can be guided by improved knowledge (e.g. Markowitz et al. 2002). We do emphasize that all future claims of inter-band correlations would benefit by simulations demonstrating their significance.

We would like the thank the following observers at Wise, who contributed their efforts

and observing time to obtain the data presented here: R. Be'eri, T. Contini, J. Dann, A. Gal-Yam, U. Giveon, A. Heller, S. Kaspi, Y. Lipkin, I. Maor, H. Mendelson, E. Ofek, A. Retter, O. Shemmer, G. Raviv, and S. Steindling. We are also grateful for the assistance of the Wise Observatory staff: S. Ben-Guigui, P. Ibbetson, and E. Mashal. T. Alexander is thanked for providing his ZDCF code.

REFERENCES

Alexander, T. 1997, in "Astronomical Time Series", eds. D. Maoz, A. Sternberg, and E.M. Leibowitz (Dordrecht: Kluwer), 163

Branduardi-Raymont, G., Sako, M., Kahn, S. M., Brinkman, A. C., Kaastra, J. S., & Page, M. J. 2001, A&A, 365, L140

Chiang, J., Reynolds, C. S., Blaes, O. M., Nowak, M. A., Murray, N., Madejski, G., Marshall, H. L., & Magdziarz, P. 2000, ApJ, 528, 292.

Clavel, J., et al. 1992, ApJ, 393, 113

Crenshaw, D.M. et al. 1996, ApJ, 470, 322

Done, C. et al. 1990, MNRAS, 243, 713

Edelson, R.A., & Krolik, J.H. 1988, ApJ, 333, 646

Edelson, R.A., et al. 1996, ApJ, 470, 364

Edelson, R., & Nandra, K. 1999, ApJ, 514, 682

Edelson, R. et al. 2000, ApJ, 534, 180

Guilbert, P.W., & Rees, M.J. 1988, MNRAS, 233, 475

Kaspi, S., et al. 1996, ApJ, 470, 336

Kaspi, S., Smith, P. S., Netzer, H., Maoz, D., Jannuzi, B. T., & Giveon, U. 2000, ApJ, 533, 631

Lee, J. C., Ogle, P. M., Canizares, C. R., Marshall, H. L., Schulz, N. S., Morales, R., Fabian, A. C., & Iwasawa, K. 2001, ApJ, 554, L13

Malkan, M.A. 1983, ApJ, 268, 582

Maoz, D., Edelson, R., & Nandra, K. 2000, AJ, 119, 119 (Paper I)

Markowitz, A. & Edelson, R. 2001, ApJ, 547, 684

Nandra, K., George, I.M., Mushotzky, R.F., Turner, T.J., & Yaqoob, T. 1997, ApJ, 477, 602

Nandra K., et al. 1998, ApJ, 505, 594

Nandra, K., Le, T., George, I. M., Edelson, R. A., Mushotzky, R. F., Peterson, B. M., & Turner, T. J. 2000, ApJ, 544, 734.

Peterson, B. M. et al. 2000, ApJ, 542, 161

Poutanen, J. & Fabian, A.C. 1999, MNRAS, 306, L31

Sako, M. et al. 2002, ApJ, astro-ph.0112436

Shields, G.A. 1978, Nature, 272, 706

Shih, D.C., Iwasaw, K., & Fabian, A.C. 2002, MNRAS, in press, astro-ph/0202432

Sunyaev, R.A., & Truemper, J. 1979, Nature, 279, 506

Uttley, P., McHardy, I. M., Papadakis, I. E., Cagnoni, I., & Fruscione, A. 2000, MNRAS, 312, 880

Warwick, R.S., et al. 1996, ApJ, 470, 349

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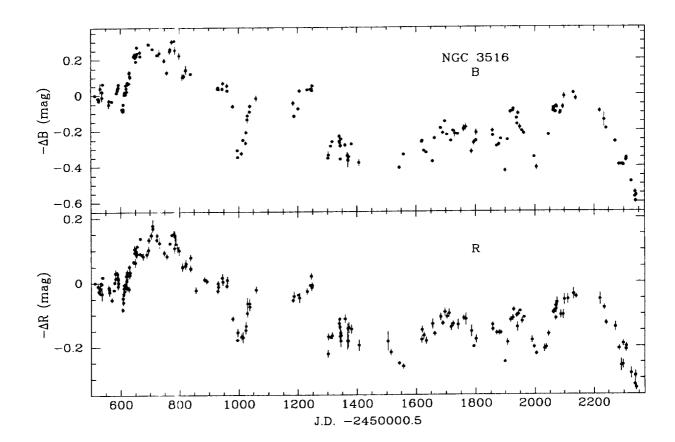


Fig. 1.— B-band (top panel) and R-band (bottom panel) light curves for NGC 3516.

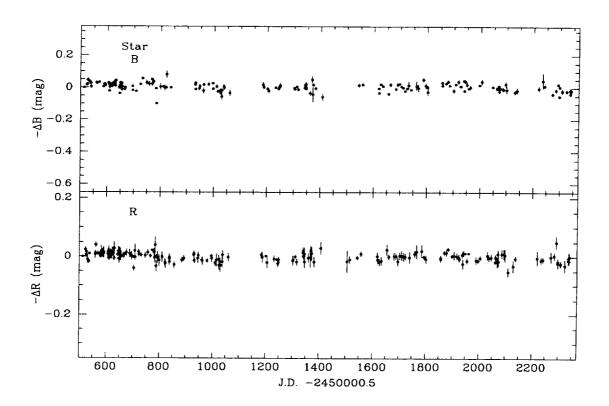


Fig. 2.— B-band (top panel) and R-band (bottom panel) light curves for one of the comparison stars, measured in the same way as the Seyfert nucleus.

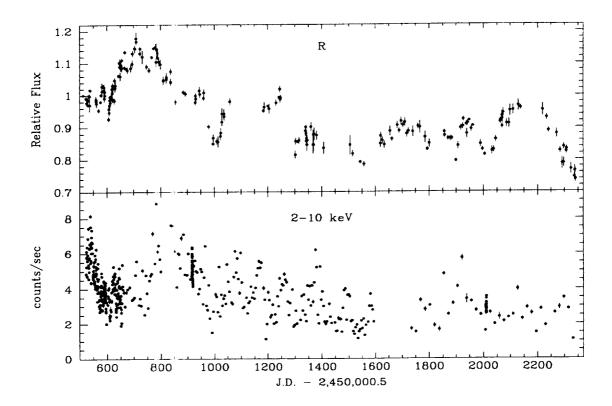


Fig. 3.— Top panel: R-band light curve of NGC 3516, but with linear relative flux scale. Bottom panel: RXTE X-ray (2-10 keV) light curve.

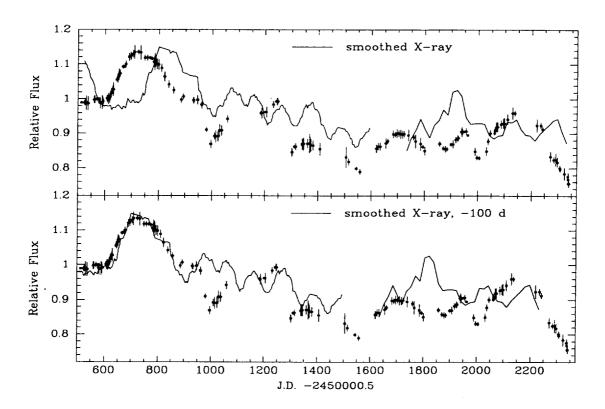


Fig. 4.— R-band light curve (boxes) and X-ray light curve (solid line), both after smoothing with a 30-day boxcar running mean. All fluxes are plotted on a relative linear scale, but the amplitude of the smoothed X-ray variations is scaled down by a factor of 4. Top panel shows the two light curves with no lag, and bottom panel shows them with the X-rays advanced by 100 days. Note how the excellent match of the first year at 100-day lag does not persist.

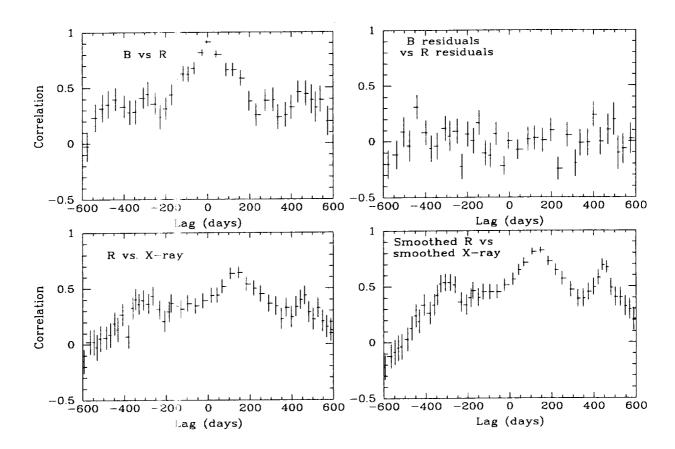


Fig. 5.— ZDCF cross-correlations. Top panel: R-band vs. X-ray light curves. Middle panel: Same as above, but after the light curves have been smoothed with a 30-day boxcar running mean (see Fig. 3). Bottom panel: As above, but between the fast components of the X-ray and R-band light curves, which are obtained by subtracting from each light curve its smoothed version.

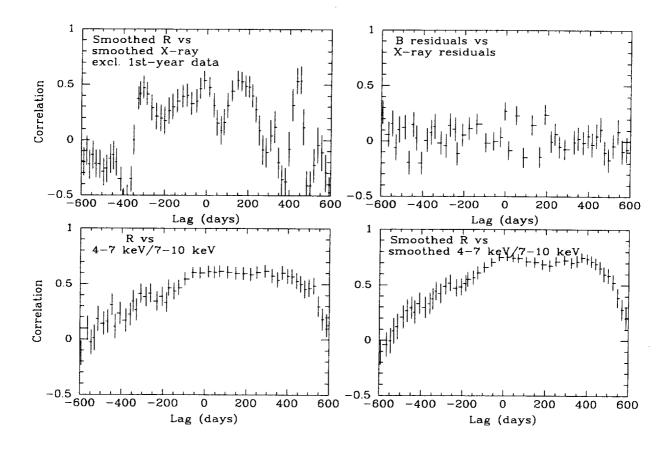


Fig. 6.— Additional cross-correlations, as in Fig. 5. Top left panel shows how the exclusion of the first year's data removes the high correlation at any clear lag between the X-rays and the optical. In the bottom panels, the R light curve is cross-correlated with the "softness ratio" of counts in the 4-7 kev and 7-10 keV bands, and with its temporally smoothed version.

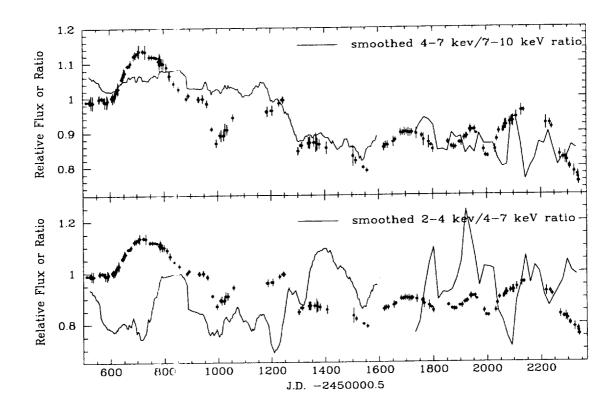


Fig. 7.— Top panel: Comparison of the smoothed R light curve (boxes) to the smoothed 4-7 keV/ 7-10 keV count ratio vs. time (solid line). To ease comparison, both time series are plotted on a relative scale normalized to unity. Bottom panel: same, for the 2-4 keV/4-7 keV count ratio.

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